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XLIII. *Experiments on Animals and Vegetables, with respect to the Power of producing Heat.* By John Hunter, F. R. S.

Redde, June 22, 1775.

THE ingenious experiments and observations lately presented to this learned Society, upon a power which animals seem to possess of generating cold, induced me to look over my notes of certain experiments and observations made in the year 1766, which indicate an opposite power in animals; whereby they are capable of resisting any external cold while alive, by generating within themselves a degree of heat sufficient to counteract it. These experiments were not originally instituted in view of the discovery, which in the event resulted from them, but for a very different purpose; which was no other than to satisfy myself, whether an animal could retain life after it was frozen, as had been confidently asserted both of fish and snakes. I mention this, to account for what might otherwise be attributed to negligence and inattention; namely, that little nicety was used in measuring the precise degrees of the cold applied in these experiments. Accuracy in this particular was not aimed at, being of no consequence in the

inquiry more immediately before me. The cold produced was first by means of ice and snow with *sal ammoniac* or sea-salt, and was about 10° of FAHRENHEIT'S thermometer. Then ice, so cooled, was mixed with spirit of nitre; but what degree of cold was thus produced I did not examine. This cold mixture was made in a tub surrounded with woollen cloths, and covered with the same, to prevent the effects of the heat of the atmosphere upon the mixture itself, and to preserve as much as possible a cold atmosphere within the vessel. The animal juices, the blood for example, freeze at 25° ; so that a piece of dead flesh could be frozen in such an atmosphere.

EXPERIMENTS.

1. The first experiment was made on two carp. They were put into a glass vessel with common river water, and the vessel put into the freezing mixture; the water did not freeze fast enough; and therefore, to make it freeze sooner, we put in as much cooled snow as to make the whole thick. The snow round the carp melted; we put in more fresh snow, which melted also; and this was repeated several times, till we grew tired, and at last left them covered up in the yard, to freeze by the joint operation of the surrounding mixture and the natural cold of the atmosphere. They were frozen at last, after having exhausted the whole powers of life in the production of heat. That this was really the case, could not be known, till I had completed that part of the experiment,

riment, for which the whole was begun; *viz.* the thawing of the animals. This was done very gradually; but the animals did not with flexibility recover life. While in this cold, they shewed signs of great uneasiness by their violent motions. In some of these experiments, where air was made the conductor of the cold and heat, that the heat might be more readily carried off from the animal, a leaden vessel was used. It was small for the same reason; and as it was necessary, for the animal's respiration, that the mouth of the vessel should communicate with the open air, it was made pretty deep, that the cold of the atmosphere round the animal might not be diminished fast by the warmth of the open air, which would have spoiled it as a conductor.

II. The second experiment was upon a dormouse. The vessel was sunk in the cold mixture almost to its edge. The atmosphere round the animal soon cooled; its breath froze as it came from the mouth; an hoar-frost gathered on its whiskers, and on all the inside of the vessel; and the external ends of the hair became covered with the same. While this was going on, the animal shewed signs of great uneasiness: sometimes it would coil itself into a round form, to preserve its extremities, and confine its heat; but finding that ineffectual, it then endeavoured to make its escape^(a); its motions became less violent by

(a) This shews, that cold, carried to a great degree, rather rouses the animal into action than depresses it; but it would appear, from many circumstances and observations, that a certain degree of cold produces inactivity both in the living and sensitive principle, which will be farther illustrated hereafter.

the sinking of the vital powers; and its feet were frozen; but we were not able to keep up the cold a sufficient time to freeze the whole animal, its hair being such a bad conductor of heat, that the consumption was not more, than the animal powers were capable of supporting^(b).

III. The third experiment was made upon another dormouse. From the failure of the last experiment, I took care that the hair should not a second time be an obstruction to the success of our experiment. I therefore first wetted it all over, that the heat of the animal might be more instantaneously carried off; and then it was put into the leaden vessel. The whole was put into the cold mixture as before. The animal soon gave signs of its feeling the cold, by repeated attempts to make its escape. The breath, and the evaporating water from its body were soon frozen, and appeared like a hoar-frost on the sides of the vessel, and on its whiskers; but while the vigour of life lasted, it defied the approach of the cold. However, from the hair being wet, and thereby rendered a good conductor of heat, there was a much greater consumption of it than in the former experiment. This hastened on a diminution of the power of producing it. The animal died, and soon became stiff; upon thawing it, we found it was dead.

(b) These experiments were made in presence of Dr. GEORGE FORDYCE and Dr. ERWIN, teacher of Chemistry at Glasgow; the latter of whom came in accidentally in the middle of our operations.

IV. The fourth experiment was upon a toad. It was put into water just deep enough not to cover its mouth, and the whole was put into the cold mixture, now between 10° and 15° . It allowed the water to freeze close to it, which as it were closed it in; but the animal did not die, and therefore was not frozen: however, it hardly ever recovered the use of its limbs.

V. The fifth experiment was with a snail, which froze very soon, in a cold between 10° and 13° ; but this experiment was made in the winter, when the living powers of those animals are very weak: it might have resisted the cold more strongly in the summer.

To ascertain whether vegetables could be frozen, and afterwards retain all their properties when thawed, or had the same power of generating heat with animals, I made several experiments. Vegetable juices when squeezed out of a green plant, such as cabbage and spinach, froze in a cold about 29° ; and between 29° and 30° thawed again, which is about 4° above the point at which the animal juices freeze and thaw.

I took a young growing bean, about three inches long in the stalk, and put it into the leaden vessel with common water, and then immersed the whole into the cold mixture. The water very soon froze all round it; however, the bean itself took up a longer time in freezing than the same quantity of water would have done; yet it did freeze, and was afterwards thawed, and planted in the ground, but it soon withered.

The same experiment

riment was made upon the bulbous roots of tulips, and with the same success.

II. A young Scotch fir, which had two compleat shoots and a third growing, and which consequently was in its third year, was put into the cold mixture which was between 15° and 17° . The last shoot froze with great difficulty, which appeared to be owing in some measure to the repulsion between the plant and the water. When thawed, the young shoot was found flaccid. It was planted; the first and second shoot we found retained life, while the third, or growing shoot, withered.

III. A young shoot of growing oats with three leaves, had one of the leaves put into the cold mixture at 22° , and it soon was frozen. The roots were next put in, but did not freeze; and when put into the ground, the whole grew, excepting the leaf which had been frozen. The same experiment was made upon the leaves and roots of a young bean, and attended with the same success.

IV. A leaf taken from a growing bean was put into the cold mixture, and frozen, and afterwards thawed, which served as a standard. Another fresh leaf was taken and bent in the middle upon itself; a small shallow leaden vessel was put upon the top of the cold mixture, and the two leaves put upon its bottom; but one-half of each leaf was not allowed to touch the vessel by the bend; the cold mixture was between 17° and 15° , and the atmosphere at 22° . The surfaces of the two leaves which were in contact with the lead were soon frozen

frozen in both; but those surfaces which rose at right angles, and were therefore only in contact with the cold atmosphere, did not freeze in equal times; the one that had gone through this process before, froze much sooner than the fresh one. The above experiment was repeated when the cold mixture was at 25° , 24° , and the atmosphere nearly the same, and with the same success; only the leaves were longer in freezing, especially the fresh leaf.

V. The vegetable juices above mentioned being frozen in the leaden vessel, the cold mixture at 28° , and the atmosphere the same, a growing fir-shoot was laid upon the surface, also a bean-leaf; and upon remaining there some minutes, they were found to have thawed the surface on which they lay. This I thought might arise from the greater warmth of these substances at the time of application; but by moving the fir-shoot to another part, we had the same effect produced.

VI. A fresh leaf of a bean was exactly weighed; it was then put into the cold atmosphere and frozen. In this state it was put back into the same scale, and allowed to thaw. No alteration in the weight was produced.

It appears from the above experiments, that an animal must be deprived of life before it can be frozen. Secondly, that there is an exertion, or an expence of animal powers, in doing this, in proportion to the necessity; and that the whole animal life may be exhausted in this way. Thirdly, that this power is in proportion to
the

the perfection of the animal, the natural heat proper to each species, and to each age. It may also perhaps depend, in some degree, on other circumstances not hitherto observed: for from experiment II. and III. upon dormice, I found that in these animals, which are of a constitution to retain nearly the same heat in all temperatures of the air, it required the greatest cold I could produce to overcome this power; while in experiment IV. and V. this power in the toad and snail, whose natural heat is not always the same, but is altered very materially according to the external heat or cold, was exhausted in a degree of cold not exceeding 10° or 15° : and the snail being the most imperfect of the two, its powers of generating heat were by much the weakest.

That the imperfect animals will allow of a considerable variation in their temperature of heat and cold, is proved by the following experiments. The thermometer being at 45° , having introduced the ball by the mouth into the stomach of a frog, which had been exposed to the same cold, it rose to 49° . I then put the frog into an atmosphere made warm by heated water, and allowed it to stay there twenty minutes; when, upon introducing the thermometer into the stomach, it raised the quicksilver to 64° . But to what degree the more imperfect animals are capable of being rendered hotter and colder, at one time then another, I have not been able to determine. The torpidity of these animals in our winter is probably owing to the great change wrought in their temperature

by the external heat and cold. The cold in their bodies is carried to such a degree, as in great measure to put a stop, while it lasts, to the vital functions. In warmer climates no such effect is produced. In this respect they resemble vegetables.

From the foregoing experiments it appears; first, that plants when in a state of actual vegetation, or even in such a state as to be capable of vegetating under certain circumstances, must be deprived of their principle of vegetation before they can be frozen. Secondly, Vegetables have a power within themselves of producing or generating heat; but not always in proportion to the diminution of heat by application of cold, so as to retain at all times an uniform degree of heat: for the internal temperature of vegetables is susceptible of variations to a much greater extent indeed than that of the more imperfect animals; but still within certain limits. Beyond these limits the principle of vegetable, as of animal life, resists any further change. Thirdly, the heat of vegetables varies, according to the temperature of the medium in which they are, which we discover by varying that temperature, and observing the heat of the vegetable. Fourthly, the expence of the vegetating powers in this case is proportioned to the necessity, and the whole vegetable powers may be exhausted in this way. Fifthly, this power is most probably in proportion to the perfection of the plant, the natural heat proper to each species, and the age of each individual. It may also perhaps depend, in some degree, on other circumstances not hitherto observed; for in experiment

periment II. the old shoot did not lose its powers, while that which was young or growing did; and in experiment III. and IV. we found, that the young growing shoot of the fir was with great difficulty frozen at 10° , while a bean-leaf was easily frozen at 22° ; and in experiment V. the young shoot of the fir thawed the ice at 28° , much faster than the leaf of the bean. Sixthly, it is probably, by means of this principle, that vegetables are adapted to different climates. Seventhly, that suspension of the functions of vegetable life, which takes place during the winter season, is probably owing to their being susceptible of such a great variation of internal temperature. Eighthly, the roots of vegetables are capable of resisting cold more than the stem or leaf; therefore, though the stem be killed by cold, the root may be preserved, as daily experience evinces. The texture of vegetables alters very much by the loss of life, especially those which are watry and young; from being brittle and crisp they become tough and flexible. The leaf of a bean when in full health is thick and maffy, repels water as if greasy, and will often break before it is considerably bent; but if it is killed slowly by cold, it will lose all these properties, becoming then pliable and flaccid; deprived of its power of repelling water, it is easily made wet, and appears like boiled greens. If killed quickly, by being frozen immediately, it will remain in the same state as when alive; but upon thawing, will immediately loose all its former texture. This is so

remarkable, that it would induce one to believe, that it lost considerably of its substance; but from experiment VI. it is evident that it does not. The same thing happens to a plant when killed by electricity^(c). If a growing juicy plant receives a stroke of electricity sufficient to kill it, its leaves droop, and the whole becomes flexible.

So far animal and vegetable life appear to be the same; yet an animal and a vegetable differ in one very material circumstance, which it may be proper to take particular notice of in this place, as it shews itself with remarkable evidence in these experiments. An animal is equally old in all its parts, excepting where new parts are formed in consequence of diseases; and we find, that these new or young parts in animals, like the young shoots of vegetables, are not able to support life equally with the old; but every plant has in it a series of ages. According to its years, it has parts of all the successive ages from its first formation; each part having powers equal to its age, and each part, in this respect, being similar to animals of so many different ages. Youth in all cases is a state of imperfection; for we find that few animals that come into the world in winter live, unless they are particularly taken care of; and we may observe the same of vegetables. I found that a young plant

(c) To kill a whole plant by electricity, it is necessary to apply the conductor, or give a shock to every projecting part; for any part that is out of the line of direction will still retain life.

was more easily killed than an old one; as also the youngest part of the same plant.

This power of generating heat seems to be peculiar to animals and vegetables while alive. It is in both a power only of opposition and resistance; for it is not found to exert itself spontaneously and unprovoked; but must always be excited by the energy of some external frigorific agent. In animals it does not depend on the motion of the blood, as some have supposed, because it belongs to animals who have no circulation; besides, the nose of a dog, which is nearly always of the same heat in all temperatures of the air, is well supplied with blood: nor can it be said to depend upon the nervous system, for it is found in animals that have neither brain or nerves. It is then most probable, that it depends on some other principle peculiar to both, and which is one of the properties of life; which can, and does, act independently of circulation, sensation, and volition; *viz.* that power which preserves and regulates the internal machine, and which appears to be common to animals and vegetables. This principle is in the most perfect state when the body is in health, and in many deviations from that state, we find that its action is extremely uncertain and irregular; sometimes rising higher than the standard, and at other times falling much below it. Instances of this we have in different diseases, and even in the same disease, in very short intervals of time. A very remarkable one fell under my own observation, in a gentleman who was taken with an

apoplectic fit; while he lay insensible in bed, and covered with blankets, I found that his whole body would, in an instant, become extremely cold in every part; continue so for some time; and, in as short a time, he would become extremely hot. While this was going on for several hours alternately, there was no sensible alteration in his pulse.